USC Center for Sustainability Solutions

A New Approach to Measuring Climate Change Impacts and Adaptation

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Motivation

- It is unlikely that International Organizations and the U.S. Federal Government will make progress on comprehensive climate mitigation programs

- Failure to achieve climate mitigation goals puts even more pressure on developing strategies for climate adaptation

Motivation

- To advance on Climate Adaptation Strategies, need to understand 2 key issues:

  - How to conceptualize and empirically measure Climate Change – the need to disentangle short-run/unexpected shocks from changes in long-run trends

  - How to define and measure Adaptation – how much adaptation could potentially be achieved through policy and regulatory frameworks

Purpose of the Paper

- Develop a new approach to measuring climate impacts; define and measure adaptation
  - Decompose meteorological variables into 2 components
    - Long-run trends - measured as monthly moving averages from the previous 3 decades
    - Short-run (unexpected) shocks - measured as deviation from the 30-year MA (climate normal)
  - To measure climate impacts and adaptation - use those 2 components associated with climate in the <u>same</u> estimating equation
  - Working concept of Adaptation - difference between the impact of the trend and the shock

Purpose of the Paper

- Provide some of the first estimates of the relative role of ‘regulation-induced’ vis-à-vis ‘residual’ adaptation
  - Ideal application: Impact of Climate on Ozone and the so-called “Climate Penalty”
    - Role that Climatic variables play in Ozone formation and the relatively short time it takes for the production to occur
    - Seasonality of Ozone – similar to ‘climate experiment’
    - Ozone is regulated under the Clean Air Act – allowing for comparing how non-attainment/attainment counties adapt

3 main sources of Data spanning multiple decades

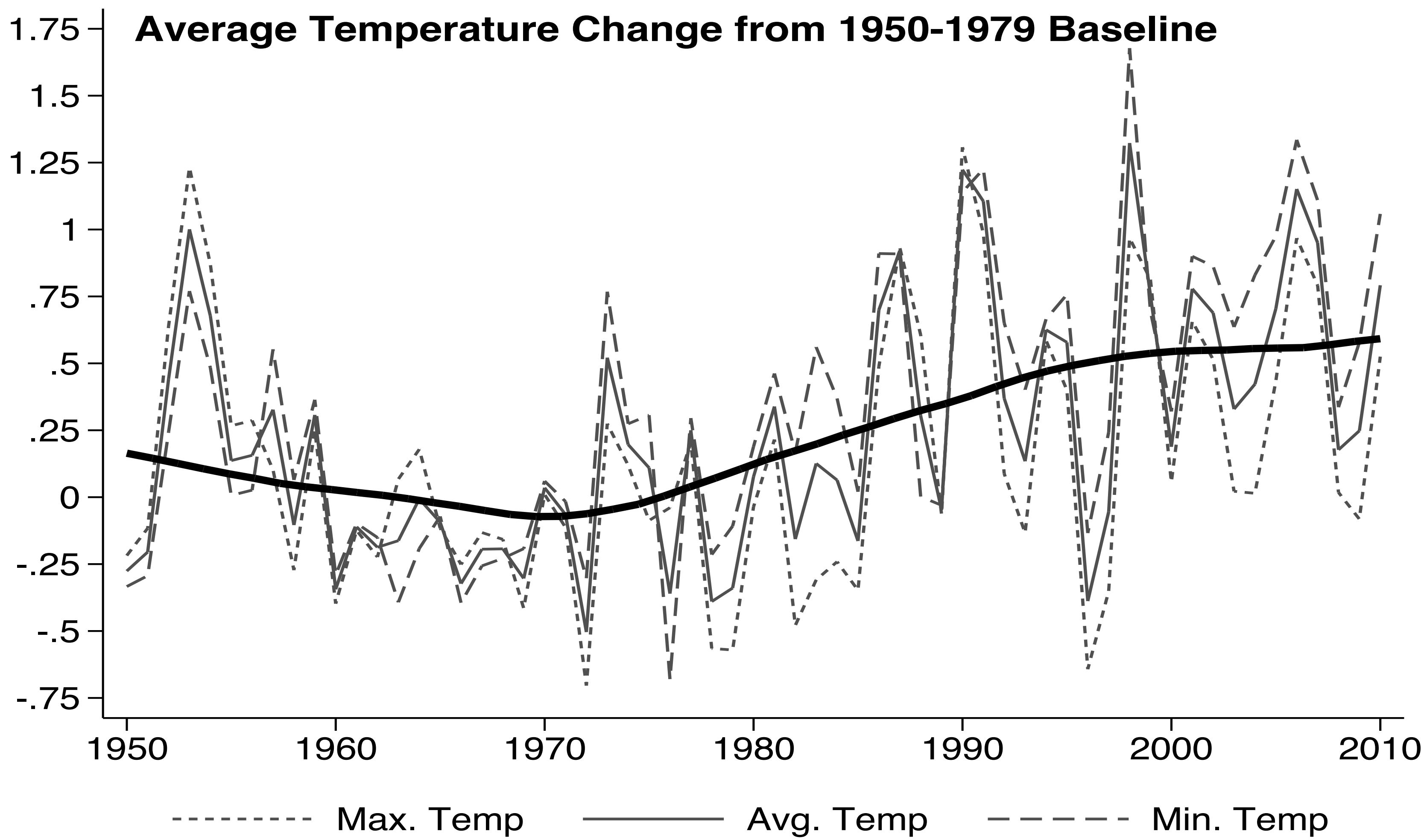
- Ozone Data – daily readings from the nationwide network of EPA’s air quality monitoring stations
    - unbalanced panel of monitors with valid information in the Ozone Season (April-September)
- Attainment Designations – data on the attainment designations at the county level (EPA and Green Book of Non-Attainment areas for criteria pollutants)
- Weather Data – daily measurements of maximum and minimum temperature as well as total precipitation from NOAA

Measurement of Climate Change: Trends and Shocks

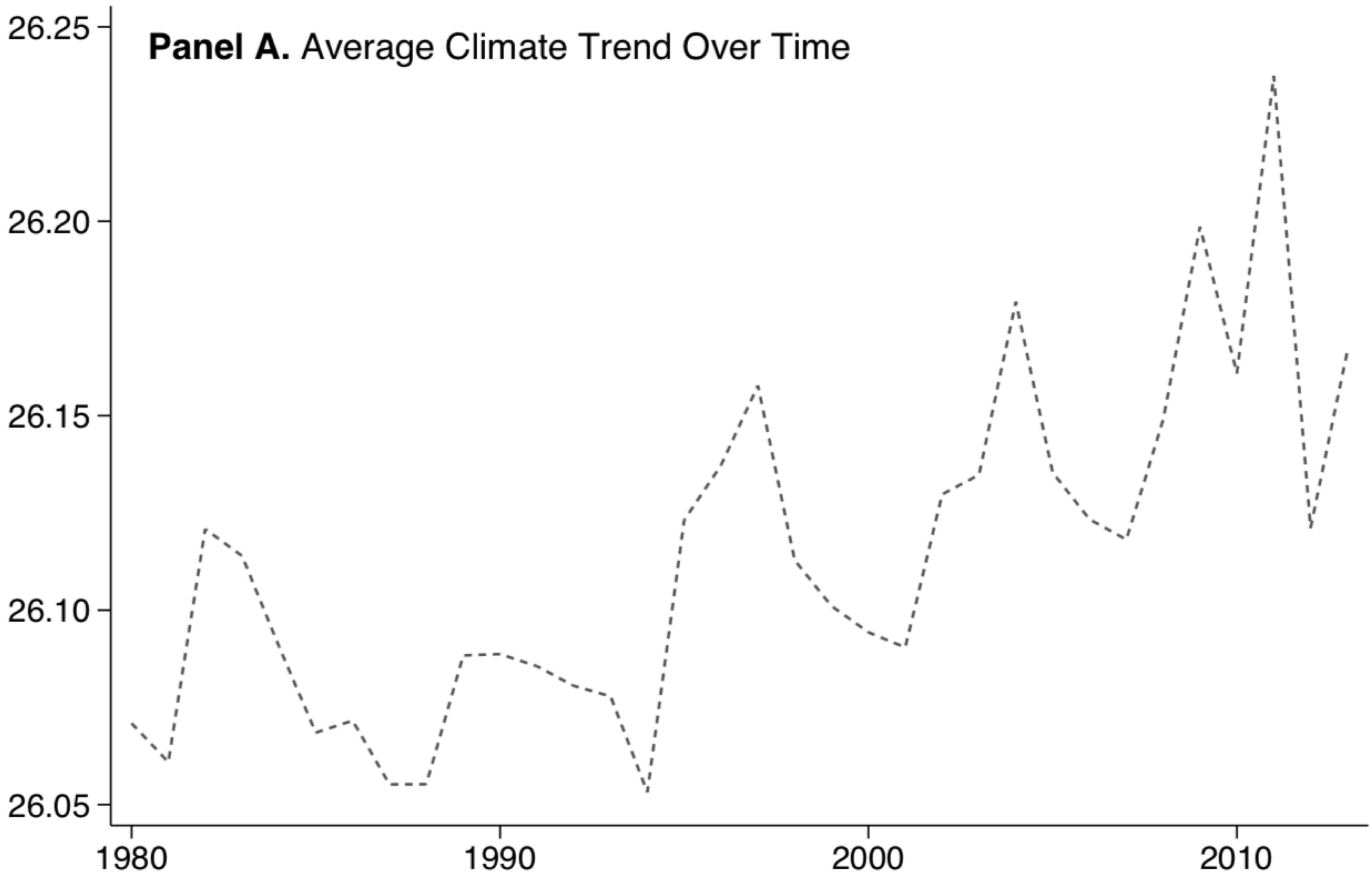
$$Temp_{idmy} = Temp^{C}_{im,y-1} + Temp^{W}_{idmy}$$

- $Temp^C$ – 30-year MA of past temp (Climate Normal)
  - we consider monthly MAs because it is more likely that individuals recall climate patterns by month
    - example: the 30-year MA associated with May 1982 is the average of May temperatures for all years in the period of 1952-1981
    - to make this variable part of the information set held by agents, we lag it by one year (robustness checks): potential for adaptation
- $Temp^W$ – weather shock measured as the deviation of the daily temperature from the lagged 30-year monthly MA
  - these shocks are revealed to economic agents only at the time when the outcome variable of interest is being measured: limited potential for adaptation

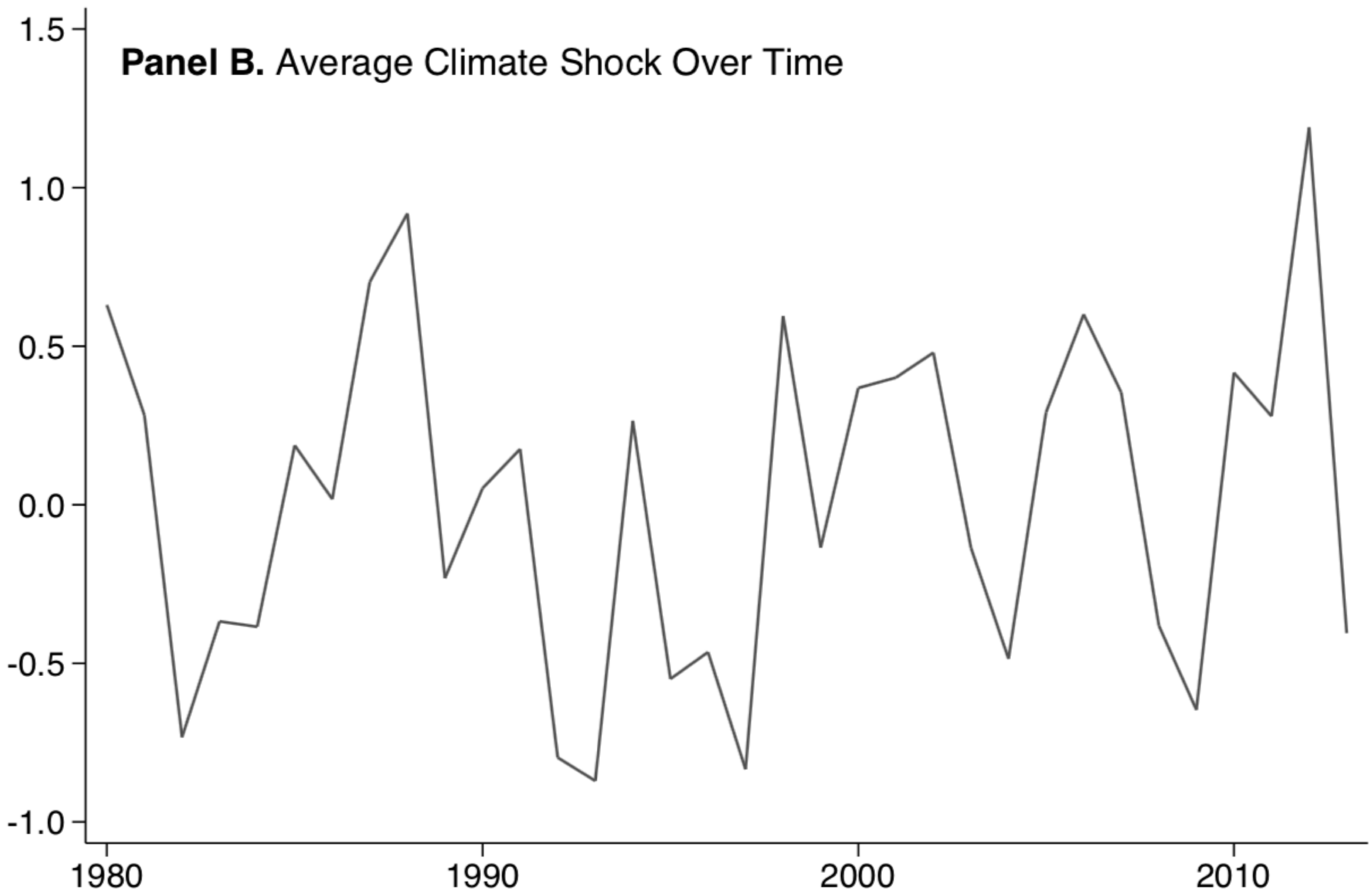
Average Temperature in the US



Measurement of Climate Change: Average Climate Trend



Measurement of Climate Change: Climate Shock



Empirical Strategy

$$Ozone_{icdmy} = \alpha + \beta_T^W Temp_{idmy}^W + \beta_T^C Temp_{im,y-1}^C + \gamma CAANAS_{c,y-3}$$
$$+ Prcp_{icdmy}\delta + \lambda_{sy} Z_i + \eta_i + \phi_{rsy} + \varepsilon_{idmy},$$

where i represents an ozone monitor located in county c in NOAA climate region r,
and d stands for day, m for month, s for season (Spring or Summer), and y for year

CAANAS (Clean Air Act Non-Attainment Status): binary variable equals to one for
counties out of attainment with the NAAQS for Ozone

Z represents time-invariant covariates (latitude and longitude of ozone monitors), which
are interacted with season-by-year fixed effects

Φ represents region-by-season-by-year fixed effects

Empirical Strategy

$$Ozone_{icdmy} = \alpha + \beta_T^W Temp_{idmy}^W + \beta_T^C Temp_{im,y-1}^C + \gamma CAANAS_{c,y-3} + Prcp_{icdmy}\delta + \lambda_{sy} Z_i + \eta_i + \phi_{rsy} + \varepsilon_{idmy},$$

- Exploit random, daily variation in weather, and monthly variation in climate normals within a season
- Identification of the impact of weather shocks – monitor level daily variation in the deviation of meteorological variables from lagged climate normals, after controlling for regional shocks at the season-by-year level
- Identification of the impact of climate trend changes – monitor level monthly variation in lagged 30-year MA of meteorological variables after controlling for regional shocks at the season-by-year level
  - we ask: what happens to Ozone in a May 1982 day when the normal temp. around the monitor in May 1981 is 1^{o}C warmer than the average of all 30-year monthly MAs of temperature in the Northeast in the Spring of 1981?

Empirical Strategy

$$
\begin{aligned}
Ozone_{icdmy} = {} & \alpha + \beta_{TA}^{W}(Temp_{idmy}^{W} \times CAAAS_{c,y-3}) + \beta_{TA}^{C}(Temp_{im,y-1}^{C} \times CAAAS_{c,y-3}) \\
& + \beta_{TN}^{W}(Temp_{idmy}^{W} \times CAANAS_{c,y-3}) + \beta_{TN}^{C}(Temp_{im,y-1}^{C} \times CAANAS_{c,y-3}) \\
& + \gamma CAANAS_{c,y-3} + Prcp_{icdmy}\delta + \lambda_{sy}Z_i + \eta_i + \phi_{rsy} + \varepsilon_{idmy},
\end{aligned}
$$

Interact two components of temperature with attainment status (CAAAS) and non-attainment status (CAANAS) to uncover measures of ‘regulation-induced’ vs. ‘residual’ adaptation

	Daily Max Ozone Levels (ppb)		Adaptation	
	I	II	III	IV
Temperature Shock	1.6942***			
	(0.0254)			
Climate Trend	1.2423***		0.4519***	
	(0.0239)		(0.021)	
Attainment x Shock		1.3025***		
		(0.0191)		
Attainment x Trend		0.9767***		0.3258***
		(0.0219)		(0.020)
Non-Attainment x Shock		1.9991***		
		(0.0335)		
Non-Attainment x Trend		1.4509***		0.5482***
		(0.0283)		(0.029)
Observations	4,974,155	4,974,155		
R^2	0.4225	0.4286		

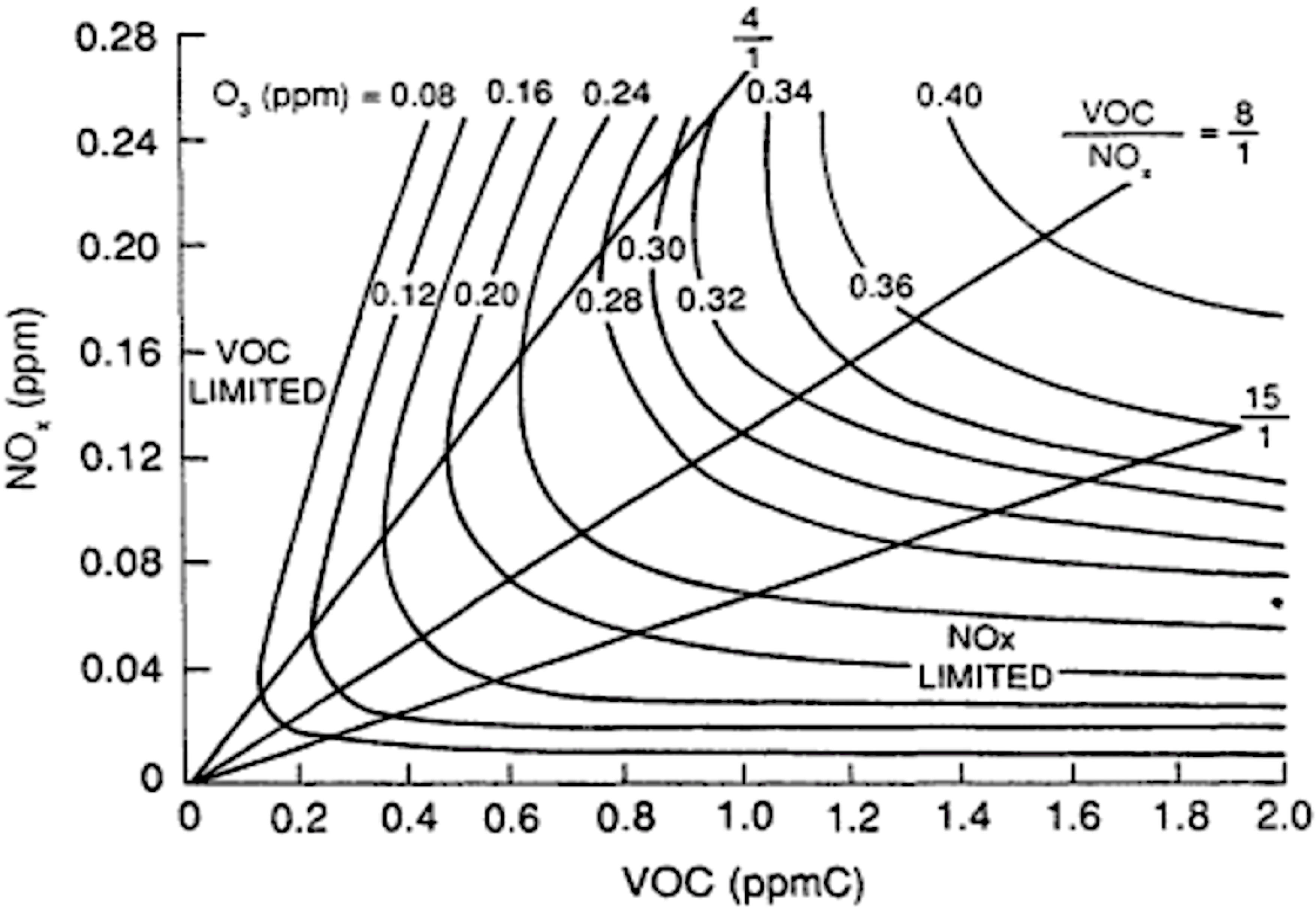
Robustness Checks

- Concern with attenuation bias from measurement error in the climate trend– vary lengths of the Climate Trend – 3, 5, 10, and 20 years moving average;

- Concern about the amount of time given to the economic agent to respond to changes in the climate trend – central specification give 1 year, robustness: allow for 10 and 20 years – suggestive of myopic behavior, since it appears that agents respond mostly to the more recent changes

- Concern about potential underestimation of temperature shocks due to opportunities of immediate adaptation – look at action day forecasts (ozone alert) and interact with shock; find nothing

Ozone Formation:
A Leontief-style Production Function



Differential adaptation based on VOC/NOX?

	Daily Max Ozone Levels (ppb)					
	Main Specification Limited Sample		Limited Counties Limited Sample		Limited Counties Adaptation	
	I	II	III	IV	V	VI
Temperature Shock	2.0848***		2.1360***			
	(0.0506)		(0.0600)			
x VOC-Limited			−0.0954			
			(0.0529)			
x NOx-Limited			−0.5195***			
			(0.1314)			
Climate Trend	1.4598***		1.4829***		0.6531***	
	(0.0520)		(0.0563)		(0.0545)	
x VOC-Limited			−0.0255		−0.0698	
			(0.0527)		(0.0614)	
x NOx-Limited			−0.4023***		−0.1172	
			(0.0831)		(0.1300)	

Steps:

- Created terciles of the VOC/NOX ratio
- Interacted the shock and trend with the bottom and top tercile;

temperature shock reflects the middle tercile; if production function of Ozone is correct interaction should be higher in the middle tercile

Are there limits to Adaptation?

	Daily Max Ozone Levels (ppb)			
	Near NAAQS		Adaptation	
	I	II	III	IV
Temperature Shock	0.5168***			
	(0.0108)			
Climate Trend	0.4930***		0.0238*	
	(0.0110)		(0.0110)	
Attainment x Shock		0.3876***		
		(0.0100)		
Attainment x Trend		0.3970***		−0.0094
		(0.0108)		(0.0093)
Non-Attainment x Shock		0.6069***		
		(0.0145)		
Non-Attainment x Trend		0.5757***		0.0312*
		(0.0132)		(0.0155)
Observations		670,122		
R^2		0.8260		

Further evidence on the limits to adaptation

	Daily Max Ozone Levels (ppb)	
	AQI Category	Adaptation
	I	II
AQI Good x Shock	0.6481***	
	(0.0105)	
AQI Good x Trend	0.2912***	0.357***
	(0.0140)	(0.015)
AQI Moderate x Shock	0.8400***	
	(0.0171)	
AQI Moderate x Trend	0.7244***	0.116***
	(0.0135)	(0.014)
AQI Sensitive x Shock	1.2885***	
	(0.0278)	
AQI Sensitive x Trend	1.0578***	0.231***
	(0.0153)	(0.026)
AQI Unhealthy x Shock	2.3474***	
	(0.0996)	
AQI Unhealthy x Shock	1.6493***	0.698***
	(0.0473)	(0.095)
Observations	4,974,155	
R^2	0.6590	

Further heterogeneity Evidence

- Explore results by Decade – greater opportunities to adapt lead to greater adaptation; this happens in earlier decades

Welfare Costs of the Climate Penalty

	Panel A. Non-Attainment Counties				
	1°C Increase	RCP 4.5 Scenario		RCP 8.5 Scenario	
		2050	2100	2050	2100
Costs (Millions 2015USD / year)					
Without Adaptation	1,700	2,381	4,762	2,721	8,164
With Adaptation	1,234	1,728	3,456	1,975	5,925
Savings (Millions 2015USD / year)					
From Adaptation	466	652	1,305	746	2,238
NAAQS Induced Adaptation	187	264	529	302	908
	Panel B. All Counties in Sample				
Costs (Millions 2015USD / year)					
Without Adaptation	2,519	3,527	7,054	4,031	12,093
With Adaptation	1,847	2,586	5,173	2,956	8,868
Savings (Millions 2015USD / year)					
From Adaptation	672	940	1,881	1,075	3,225

Conclusions

- Proposed a new method for measuring the costs of climate change and opportunities for adaptation in a unified framework

- Allow for studying regulation-induced adaptation

- Adaptation is intuitively defined by the difference between the impact of the temperature shock and the trend

- In the context of ozone:
  - Highlighted the relevant and limits to adaptation through regulation-induced adaptation
  - Costs of climate are large, even after accounting for adaptation